INTELLIGENT SYSTEMS FOR ADVANCED MISSION OPERATIONS

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ABSTRACT

Many mission operations systems and tools have been developed over the past decades as NASA has operated the Mars Exploration Rovers, the Space Shuttle, and International Space Station. Usually there is little cross-fertilization between the unmanned mission operations systems and those used for manned spaceflight. NASA Ames Research Center has been developing and applying its advanced intelligent systems research to mission operations tools for both unmanned mars missions operations with the NASA's Jet Propulsion Laboratory since 2001 and to manned operations with NASA Johnson Space Center since 2006. In particular, the lesson learned, and experience and capabilities developed for mission operations systems for the Mars Exploration Rovers have enhanced the development and application of advanced mission operation systems for the International Space Station and future exploration spacecraft. This paper discusses the approaches and strategies that have enabled a variety of intelligent systems technologies to be demonstrated in the unmanned mission operations venues and then imported and adopted as key technologies for manned mission operations. We also discuss in several specific projects with the Johnson Space Center's Mission Operations Directorate.

1. INTRODUCTION

NASA's current space flight missions are largely segmented into unmanned missions funded by the NASA's Science Mission Directorate, and the human spaceflight missions operated by the Spaceflight Operations Mission Directorate. The unmanned missions cover earth-orbital systems as well as the planetary missions. Typically the organizations within NASA that operate the unmanned missions are different from the organizations that operated crewed space systems. The mission operations requirements and needs for the robotic missions have been relatively distinct from those for the Space Shuttle and the International Space Station (ISS).

As part of the U.S. President's Vision for Exploration, NASA plans to develop a new spacecraft, Orion, and a new launch infrastructure, Ares. NASA also plans for the return of humans to the Moon, and the eventual human exploration of Mars. The range and complexity of these exploration missions will require an unprecedented use of automation and robotics in support of human crews.

Developing and validating the new exploration spacecraft and its associated infrastructure may place requirements on operations design for near-term explorations (e.g. lunar) missions. Separate mission operations processes—and cultures—have evolved at Johnson Space Center and Jet Propulsion Laboratory, each geared to the unique challenges of the two classes of missions.[i] Thus, enabling the technologies and process innovations that benefited the robotic missions to also benefit crewed missions is not simple nor straightforward.

1.1. Mission Operations Directorate Needs

In collaboration with the NASA's Astronaut corp, the Johnson Space Center's Mission Operations Directorate (MOD) manages and maintains the flight operations of all of NASA's human spaceflights. These include all of the previous manned spaceflights from Mercury through Apollo, and now the Space Shuttle and ISS. The flight operations of the crewed elements of the exploration focused Constellation Program (CxP), such as the Crew Exploration Vehicle (CEV) or Orion, will also be managed by MOD.

Manned flight operations support is provided by the combination of several ground mission control centers around the U.S. and the World, primarily focused through the Mission Control Center (MCC) at Johnson Space Center (JSC) in Houston, Texas. The Shuttle flight operations are supported primarily by MCC and the Payload Ops Integration Center (POIC) at Marshal Space Flight Center (MSFC) in Huntsville, Alabama. The ISS is also supported by these two centers, plus the International Partners control centers including the Mission Control Center in Moscow (MCC-M or TsUP), the European Space Agency (ESA) Columbus Control Center in Germany and the ATV Control Center in France, the Canadian Space Agency (CSA) Control Center near Montreal, Canada, and the Japanese Experiment Module (JEM) and HTV Control Centers in Tsukuba, Japan.

With the retirement of the Shuttle in 2010, MOD at JSC is in the first stages of planning the Operations support activities associated with the new CEV/Orion for both the initial ISS visits and Lunar flights. MOD has stated a goal of manning the CEV flight support with approximately 50% of the manning currently required for Shuttle. This goal is based in part on the assumed simplicity of operations of the CEV as compared to the Shuttle and on assumed increased automation within the spacecraft onboard systems. MOD is restructuring itself to be more efficient in support of the "Plan, Train, and Fly" activities associated with the Constellation Program, but are also investigating several technology infusion opportunities as described within this paper which they anticipate will help in achieving this reduction goal.

Most of the effort that goes into supporting crewed flight operations is in the preparation for flight activities (the "Plan and Train" part), and the actual flight/mission support (the "Fly" part) is typically the least manpower intensive. Significant facilities infrastructure is required to accomplish the "Plan, Train, and Fly" activities, from scheduling and analysis tools, to training simulations, and the mission control center itself. Typically, several years prior to a launch or increment activity, MOD works with the program offices to understand the requirements for any given flight/increment. During this early "Plan" phase, MOD must accomplish the mission concept definition, the mission requirements integration, long and short term timeline planning, flight rules development, crew and ground procedures development, and mission analysis and design (consumables, launch and entry analysis, orbit and rendezvous design). The timelines begin as very high-level schedules of crew and ground activities which meet the requirements. These schedules are iteratively adjusted and improved as the flight/increment draws nearer, and it is often adjusted during the mission itself. The schedules are continuously improved from high-level schedules of crew/ground activities to more detailed schedules that account for hourly activities for the mission. While the negotiations for schedule details continue to require collaboration among team members and partners, new applications and tools are increasingly helping automate and adjust the layout of the activities for the missions. Similarly, new applications continue to improve the mission analysis and design processes.

The "Train" phase of the mission preparation includes training both the astronauts and the mission flight control teams. This is accomplished by a combination of classroom training, stand-alone simulations of the flight vehicle and environment, and integrated simulations where both the astronauts and the flight control team are involved in joint simulations of the missions. During these simulations, vehicle systems failures and flight constraints scripted to exercise and test the team's abilities to deal with unexpected problems. New applications, techniques and tools that enhance or provide more flexibility in the simulation environments are being assessed to improve these simulation capabilities. MOD is also utilizing more automation in the curriculum design and development process.

The "Fly" phase of the mission includes the real-time flight operations with the Flight Director, Flight Controllers, Ground Controllers (for the facilities), the Engineering support, and in the case of ISS, the International Partner operations support and integration. Within the MCC, the team is structured such that the Flight Control Room (FCR) is the focus of all mission control, with the Flight Director, CAPCOM, the vehicle systems flight control specialists, and other specialists integrally involved in making the mission decisions. For most of the positions within the MCC FCR, there are support flight controllers in the Multi-Purpose Support Rooms (MPSR) within the MCC and in some cases in remote locations (such as the Canadian ISS Robotics Support). The detailed engineering support is provided by the Mission Evaluation Room, and this team can get support as needed from the systems experts at other centers, industry, and International Partners. The mission management team keeps an overview of the ongoing flight activities and provides any Programmatic-level decisions that are needed. Note that while MCC Houston is the lead for overall flight planning and core systems assessments, for the ISS, the POIC at MSFC integrates the payloads, and the International Partner Mission Control Centers are primarily responsible for their own modules. MOD is assessing several new Ames-developed technologies and tools to enhance the real-time mission support environment including better search tools for flight-related information, a more interactive display building environment, and telemetry monitoring and agent-based support tools to off-load the work of the flight controllers. For all these technology improvements to the mission support ("Plan, Train, Fly), MOD is using the current ISS support environment as a test-bed.

Traditionally, past crewed NASA missions have been highly dependent upon earth-based mission operations. Crewed missions hardware and software systems are programmed to be capable of dealing with many unanticipated events, but most of the flexibility of the crewed missions comes from the crew itself and the ability of the earth-based flight controller to adapt and handle any situation. This means that the primary responsibility for handling unforeseen situations always resides with humans, who are either onboard the spacecraft or in mission control.

1.2. MOD's Flight Operations Improvement Team

In 2006, MOD chartered the Flight Operations Improvement Team (FOIT) to evaluate the processes, structures, and technical approaches that mission operations would need to support the Vision for Space Exploration, and the new Constellation Program.

As part of the FOIT, a team assessed what automation would be required to exist to support mission operations (both earth-based and on-board decisions)[ii]. Several areas of automation where determined to be highly valuable, including,

- Solar array sun tracking, antenna/satellite tracking
- Scripted procedures
- FDIR (fault detection isolation and recover after a system failure)

The approach suggested by the FOIT automation team was to aim for full autonomy of future exploration missions from the earth. This means that the spacecraft and crew operate without intervention from the ground. This capability is clearly required for the future Mars missions, and the Lunar missions will provide a transition to this kind of operations. This autonomy may be achieved by a combination of automated and manual functions on-board, but requires no cues from the ground. The current MOD plan to support future operations, by necessity, is to evolve their existing operations systems, processes and capabilities to support this future Orion and exploration autonomy concept. This means MOD wants to incorporate automation capability within ground operational practices at the beginning of the first flight of the Orion to the maximum extent possible. Preparing for this improved operations automation must be a staged process where it is necessary to assess what are the components of the future operations that are desired to be either on-board or earth-based[iii]. Then knowing conceptually what are the future operational models to be striven for, to incorporate augmented automation capability within operational practices of the Mission Operations Directorate.

The FOIT study recommended several conceptual constraints upon future spacecraft, such as "Design a vehicle that can be automated safely." However the most significant recommendations were focused upon the overall operations strategy. This applies equally to the existing ground-based operational infrastructure used by MOD and the future goal of operations. These are (in part);

- Utilize automation where it makes sense… and define up front what makes sense.
- Let flight experience dictate what functions should be automated. Focus automation capability where requirements and vehicle functionality are clear and well understood. Phase in automation of complex operations as those operations mature.
- Define roles & responsibilities up front. Clarify expectations and requirements for all phases of related development, delivery, and utilization. More specifically, clarify the transition points for authority and responsibility between all organizations involved in automation development and implementation.
- Address interactions with other areas of MOD responsibility: MCC, recon, training, procedure development, ops planning.
- Allocate responsibility for developing automation products that are not embedded in flight software to Mission Operations.

For example, to evolve from the existing practices operating the ISS required the assessment of what gaps exist in progressively making ISS more automated. This would initially not require more autonomy from the ground, but would mean that the current ISS operations would be targeted for increase efficiency and automated systems would looked at to reduce flight controller workload. By using the ISS operations as a demonstration and validation ground for the use of new technologies, MOD will be able to assess where, when and how additional advanced software systems will impact Constellation Program mission operations, and how those will enable the goal of an autonomy capable system for NASA's Exploration. The migration of autonomy-based mission support tools from the ground to the spacecraft will be a CxP Programmatic decision, but MOD is attempting to assess and support operational use of this technology both for ground operations improvements and for future spacecraft infusion.

The NASA mission community tends to be properly conservative about the use of new technology in mission-critical, and life-critical, situations. The automation necessary to support advanced operations is correctly perceived as involving new technology. Consequently, a realistic way to create acceptance of this new technology is to perform a series of analog operations using existing spacecraft, principally ISS, and then to begin using the technology in CEV missions as soon as practical.

In order to meet these new operational requirements it is critical that advanced operations are assumed from the beginning of the CEV development process. Operations concepts have system-of-systems implications for mission operations design, and tend to become "baked" into mission design, operational models, and culture.

1.3. Ames advanced software systems

NASA Ames Research Center has been a leader in the development of advanced software technologies and systems for NASA Missions. In the 1990s this role included leadership of NASA's automated reasoning and human-centered computing programs. Ames exercised these responsibilities to provide the Agency with a notable set of software technology "firsts," including the first autonomy software to be flown by NASA on a spacecraft[iv] the first capability to model human activity in such complex environments as planetary exploration, and the first advanced planning software to daily plan a robotic planetary mission (MAPGEN[v]). These and other accomplishments grew out of a combination of excellent technical work, a focus on NASA's needs and vision of its future, and a portfolio of activities ranging from needs-driven technology development to project-focused tool development.

Given its past accomplishments NASA Ames has taken the current exploration focus as an opportunity to address the significant challenges posed by the agency's ambitious exploration agenda in the mission operation arena. The intelligence currently provided by MOD mission controllers will need to be automated and accompany the astronauts on these future missions. Systems will need to be more adaptable for varied mission scenarios. An ability to rapidly and dependably develop and modify software could provide MOD the means to alter system capabilities on the fly. Following current practices, software modifications to space-based systems can take in the months or years to make. To modify capabilities between and during missions, revolutionary software development approaches are needed - new approaches that, in the tens of minutes, can result in effective and dependable modifications. Like MOD, in order to achieve these goals Ames must target an evolutionary path to proving out technical approaches. During this evolution it must validate the value for the crewed mission operations community.

1.4. Ames Human Centered Computing

The lessons learned from NASA Ames developers and the experience they had creating tools for the Jet Propulsion Laboratory's Mars Exploration Rover mission, and now the upcoming Mars Science Laboratory, have set a framework for how Ames is determining what opportunities exist for intelligent systems applied to the crewed spacecraft operations for NASA. Principally the discussion of new technologies and tools needs to be framed in a manner that identifies and emphasizes the value to the MOD operational flight controller. It is not about replacing 'man with a machine', but about augmenting the flight controller or operator to do a better job. This overall methodology and approach is often referred to as human centered computing.

Human centered computing looks to the processes and procedures that people do in order to perform any given job. Then with this understanding, attempts to identify opportunities to improve the processes and procedures for people to perform. In particular, for mission operations, this is quantified by specifically identifying how a tool can increase a person's efficiency, enhance a person's functional capability, and/or improve the assurance of person's decisions.

A human centered computing strategy contains the following essential elements:

- Deploy personnel to mission centers to work with the NASA customer(s) to understand the exact nature of their current and future challenges that may be amenable to software solutions.
- Scouting for all relevant approaches or technologies that may address the customer's needs.
- Identify technology gaps left by current software capabilities to seed new R&D.
- Simultaneously conduct carefully-targeted R&D to address the gaps on an ongoing basis
- Evaluate and compare competing results, working closely with the customer to determine the strengths and weaknesses and the cost-benefit of the each candidate solution and improve it on this basis.

This above strategy worked exceptionally well for infusing advanced technologies in the Mars Exploration Rover missions. MAPGEN (previously mentioned), and MERCIP[vi], the collaborative information portal for the mission operations teams both were successful solutions for flight controller challenges.

2. ADVANCED MISSION OPS PROJECTS

At the advent of the Vision for Space Exploration, Ames and JSC began discussion about how to leverage each other's strengths and capabilities. Now they have established a set of initial projects that will address outstanding needs within MOD. These projects first started in 2006 and have progressed to several full scale projects delivering operational flight controller tools in 2007. A summary overview of some of the currently projects underway is presented below.

2.1. OSTPV Enhancements

The On-Board Short Term Plan Viewer (OSTPV) is a tool used by flight controllers to view and manipulate the International Space Station's Short Term Plan (STP). This plan spans several days to 2 weeks, and describes activities performed by ISS crew and the status of major ISS subsystems at a time granularity of tens of minutes. These plans are developed using the Consolidated

Planning System (CPS), which contains rules that govern the legality of the STP. Flight controllers can manipulate the STP by re-scheduling or deleting activities; however, OSTPV only displays the new schedule, and does not perform any checks for constraints that may be violated as a consequence of plan manipulations.

OSTPV plans will be checked for constraint violations using an application built on the Extensible Universal Remote Operations Planning Architecture (EUROPA), developed at ARC. CPS rules and STPs are semi-automatically transformed into EUROPA's representation for analysis, and a report is generated for use by controllers. This collaboration started in September 2006 and is leading to a completed system to be utilized by flight planners in order to analyze ISS S-Band communication plans. A completed prototype application will be available in June of 2007, with a final application available in September of 2007. This work is planned to continue through fiscal year 2009.

2.2. Mission Operations Design and Analysis

OCAMS (OCA Mirroring System) is a practical engineering application of multi-agent systems technology, using the Business Redesign Agent-based Holistic Modeling System (Brahms) modeling and simulation tool. The Brahms system combines models of systems (e.g., robots, tools, software) with models of people communicating and moving in a simulated geographic space, revealing how interactions of people, facilities, and tools are productive or gaps that may occur in capabilities and procedures. Brahms simulations can be converted into a runtime system in which software agents mediate work flow operations and communications among people and systems.

The present project, called MODAT (Mission Operations Design & Analysis Tool), is a collaboration which began in November 2006, leading to a completed workflow automation system to be used by OCA Officers in the MPSR backroom supporting the ISS by the end of calendar year 2007. Specifically, the OCAMS tool will automate the mirroring process by which a duplicate file structure of the ISS is maintained in MCC for verification and testing. The long-term purpose of the MODAT project is to develop new mission operations design and automation capabilities that will reduce the need for ISS ground support on a 24-7 schedule. The objective in 2007 is to demonstrate of the capabilities of the Brahms methodology for redesigning a work system through a “simulation to implementation” approach.

This development methodology combines ethnography, participatory design, multi-agent simulation, and agent-based systems integration. A “current operations simulation” of the existing mirroring work practice was delivered March 2007; a functional design for the automation tool (OCAMS) was developed collaboratively with OCA Officers during April 2007. A “future operations simulation” will be delivered by the end of 2007. This hybrid simulation will flexibly combine actual systems (e.g., FTP, email) and objects (e.g., archived ISS files) with simulated people and systems (e.g., a server, the GUI). The future operations simulation will thus contain 80% of the OCAMS system, constituting a prototype tool, which will enable validating and improving the design as necessary through operations on actual data.

2.3. Inductive Monitoring System

The Inductive Monitoring System (IMS) is an Ames developed health monitoring software application that compares current system data with data from previous nominal system operations. IMS applies data mining techniques to archived telemetry to establish a baseline of normal behavior for groups of data parameters from the monitored system. IMS then uses that baseline to identify off-normal behavior in real-time telemetry, potentially prior to any caution and warning annunciation for the system. Any deviations from normal baseline behavior will be indicated by IMS with a non-zero "distance" from nominal. Information is also provided on which data parameters are contributing to the off-nominal readings to help identify the source of the anomaly.

In 2006, ARC delivered IMS based tools to JSC that allow mission operations users to retrieve archived mission data and run the data on IMS to both "train" the tool on nominal data and to execute the "monitoring" feature. This capability was tested on several ISS Control moment Gyroscope (CMG) data sets, including data collected during some significant CMG malfunctions. IMS successfully detected anomalies in CMG behavior in these data sets, sometimes several hours before malfunctions were detected by current MCC systems. These promising results prompted JSC to establish an 2007 task to deploy the tool within the MCC environment for evaluation and use by the on-console flight control team. The IMS tool has been integrated with the MCC real time data system and deployed on the ADCO mission control consoles in the ISS control room to provide real time CMG monitoring. In addition, IMS has been augmented with fault detection routines that will automatically detect and identify some common CMG faults to assist controllers in diagnosis and recovery activities. Continued on-console validation and testing of IMS is expected to result in full operational certification by August 2007. Several additional MCC applications for IMS have been identified and work to build additional IMS deployments and develop a general purpose IMS MCC application is planned to continue through 2009.

2.4. Mission Control Technologies

Current MOD mission operations systems are built as a collection of monolithic software applications. Each application serves the needs of a specific user base associated with a discipline or functional role. Designed to accomplish specific tasks, each application embodies specialized functional knowledge and has its own data storage, data models, programmatic interfaces, user interfaces, and customized business logic. In effect, each application creates its own walled-off environment. While individual applications are sometimes reused across multiple missions, it is expensive and time consuming to maintain these systems, and both costly and risky to upgrade them in the light of new requirements or modify them for new purposes. It is even more expensive to achieve new integrated activities across a set of monolithic applications.

These problems impact the life-cycle cost (especially design, development, testing, training, maintenance, and integration) of each new mission operations system. They also inhibit system innovation and evolution. This in turn hinders NASA's ability to adopt new operations paradigms, including increasingly automated space systems, such as autonomous rovers, autonomous onboard crew systems, and integrated control of human and robotic missions.

In order to achieve NASA's vision affordably and reliably, we need to consider and mature new ways to build mission control systems that overcome the problems inherent in systems of monolithic applications. Two keys to the solution are *modularity* and *interoperability.* Modularity will increase extensibility, reusability, and maintainability. Interoperability will enable composition of larger systems out of smaller parts, and make possible the construction of new integrated activities that tie together, at a deep level, the capabilities of many of the components. Modularity and interoperability together contribute to flexibility.

The Mission Control Technologies (MCT) Project, a collaboration of multiple NASA Centers, led by Ames, is building a framework (based upon the open-source Eclipse software) to enable software to be assembled from flexible collections of components and services. The ongoing work on MCT at MOD is to integrate and run MCT in the OTF, shadowing an ISS mission in the MCC. Also to develop, gather, and analyze measurements to evaluate the performance and usability of MCT, from a flight controller's perspective. Finally to define and analyze the proper engineering metrics - performance, lines of code, and the potential cost savings. As of June 2006, an initial implementation of the MCD was being tested in the MOD OTF and receiving high praise.

2.5. Search Tools

The Search Tools for MOD Flight Controllers project focuses on improving MOD access to and retrieval of critical information required to monitor, control, and manage ISS and Space Shuttle. While much of this information (in the form of notes, change requests, action item lists, procedures, documentation, etc.) is currently accessible using a patchwork of disconnected tools and databases, this project is building a unified search capability across these data sources an presenting a unified single Web-based interface for all MOD flight controllers. In addition, the system identifies cross-referenced and other relevant information that flight controllers might otherwise overlook.

This work consolidates two independent search back-ends that were initiated within MOD at different times and for different motivations. The Netmark search back-end began in October 2006 and deployed a prototype search capability to JSC/DF users in December 2006. The XSearch back-end, working closely with JSC/DO and JSC/DA, began in January 2006 and is currently testing two applications in the MAS (MOD Application Server) development environment.

The initial releases of the Search application -- a search interface and indexing programs -- will be fully integrated with the MCC Web Tools suite and deployed to flight controllers by the end of 2007. The unifiede search interface will enable MAS users to search across data sources indexed by both the Netmark and XSearch efforts. This work is planned to continue into 2008, when additional data sources will be added to the pool that can be uniformly cross-searched by MOD personnel.

2.6. CxP Training Facility

The Constellation Training Facility (CxTF) project is led by JSC/DV and is supported by personnel from Ames. The goal of the project is to define Level-B requirements in the areas of simulator data management, standalone and distributed simulation capabilities, infrastructure for the interface between the simulation platform and CEV/Orion crew stations, instructor/operator control capabilities, CLV/Ares and CEV/Orion communications and tracking systems, and ground network simulation. Mission Concept Review was held May 9, 2007, at JSC. Immediate next steps are to establish a capability for managing CxTF requirements, to implement an appropriate database management system, and to establish structured linkages to higher level requirements. The next steps will address verification methodology, data exchange with CxP requirements systems, functional allocation of instructor/operator requirements to applications, and design for accessing or integrating the MOD training scheduling system with the instructor/operator workstation. Ultimately CxTF will also address derivation of specifications or guidance for model reuse, coordination with all CxP modeling & simulation activities to enable efficient reconfiguration and model/software reuse. This project is planned to continue thorough 2010. The major Ames products expected at that time will be a physical mock-up of Orion cockpit integrated with crew display interface and health management software and simulators.

2.7. Solar Array Constraint Engine (SACE)

As the construction of the ISS continues, solar arrays are being added to provide the power required to support additional modules on the larger station. These new arrays have more freedom to articulate, enabling better tracking of the sun and thus increased power production. However, these arrays also have more complex constraints that limit the range of safe orientations, due to structural loads, contamination concerns, and thermal impacts. These limitations on safe array orientations impact power generation, which requires MOD flight controllers to constantly balance multiple complex constraints against ISS power needs. The increased complexity does not only impact pre-planning activities, but has an even more acute effect on real-time operations, in particular when handling unexpected events or changes in operations plans.

The Solar Array Constraint Engine (SACE) project has developed a tool that provides intelligent decision-support capabilities to ISS power systems flight controllers, to assist them with the task of planning and executing solar array operations in a safe and effective manner. SACE provides situational awareness, orientation evaluation and optimization, and array operations planning functionality to flight controllers. The SACE tool is built on the EUROPA engine, which provides constraint management and reasoning, decision-support and planning.

The functionality of SACE is primarily three-fold. First, SACE provides situational awareness to the flight controllers. SACE monitors the telemetry and station events, identifies applicable constraints and power needs, and then presents the flight controller with graphical information about whether there are constraint violations and whether power production meets power needs. In addition, the flight controllers are provided with contextual information that gives them at-a-glance a picture of how alternative array positions would fare in terms of constraints and power production.

Secondly, the SACE tool provides decision-making assistance to flight controllers. Flight controllers are able to specify ISS events and situations, along with candidate solar array orientations, and providing them with information on whether constraints are satisfied and power needs are met. Contextual information, in the form of various graphical maps, is also provided, making it easy for flight controllers to find good candidate solar array orientations for a given event and situation. Furthermore, the tool offers automated optimization, relieving the flight controller of finding the desired solar array orientation, and automatically suggesting it. As the desired optimal orientation differs based on situations and flight controller needs, the flight controller can specify in detail the criterion for the best solution.

Thirdly, SACE provides a solar array plan generation and editing capability. This is critical for pre-planning operations; the current manual approach will become infeasible as solar arrays are added. The tool reads specifications about planned station events, orientations and situations, and automatically generates a safe plan for operating the solar arrays, while ensuring that power needs are met, or, if they cannot, provides the best power production profile possible. The solar array plan support capability also supports on-console operations, by allowing users to modify the plan and have the plan subsequently updated as needed.

An initial version of the tool was delivered prior to the December 2006 Shuttle flight, during which the first set of new solar arrays were activated. The final version will be ready in time for the planned August 2007 Shuttle flight, when a third set of solar arrays will be activated.

3. CONCLUSION

The work that NASA's Ames Research Center and Johnson Space Center are doing for applying intelligent systems to create advanced mission operation tools and systems is critical to the Agency and the Vision for Exploration. Improving the capacity of NASA's main manned mission operations teams to handle more operations per controller, enhancing the capabilities of those teams to handle more complex decisions, and increasing the available knowledge to the flight controller to make safer decisions are the critical motivations for this work.

These are the first projects in a planned series of efforts to greatly enhance how Mission Operations are performed for human spaceflight within NASA. These efforts will prepare MOD for the more automated and autonomous exploration spacecraft that will enable NASA's exploration vision.

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